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Current and Potential Use of Technology Forecasting Tools in the Federal Government

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Executive Summary

The Intelligence Advanced Research Projects Activity (IARPA) supports research programs to develop forecasting capabilities, including technology forecasting tools, which aim to predict technology's future characteristics or applications. IARPA requested that the IDA Science and Technology Policy Institute (STPI) explore the current and potential future use of technology forecasts in science and technology (S&T) decision-making to help IARPA improve the development and implementation of S&T analytical capabilities.

The project had two main goals. The first was to understand the current state of technology forecasting in Federal Government agencies and the role that technology forecasting plays in decision-making. The second goal was to understand what technology forecasting tools are desired by Federal agencies, including the characteristics of technology forecasting tools, approaches, and information that personnel would like to use. To understand the current and potential use of technology forecasting tools and decisions in the Federal Government, STPI research staff conducted interviews with personnel at a range of Federal agencies that use information about new or emerging technologies or technology applications.

Use of Technology Forecasting in the Government

Two different models describe when and why an agency begins a technology forecasting effort: (1) as a consequence of routine surveillance and reporting requirements and (2) as a reaction to a specific event occurring or a certain need arising. The specific applications of technology forecasting may include:

- Gathering intelligence,
- Identifying threats and opportunities emerging from potential future applications of technologies (e.g., public health threats and dual-use technology applications),
- Managing research portfolios,
- Understanding how future scenarios might be shaped or affected by today's long-term technology investments, and
- Understanding economic and policy implications of the evolution and global availability of commercial technologies or products.

While these applications of technology forecasting may differ among different agencies and offices, the type of decision-making that the forecasting supports is correlated with the timescale for the forecast. In general, the agencies and offices that are interested in the state of technologies

or technology applications within 5 years are preparing to respond quickly to concerns associated with technologies that either have already reached the later stages of technology readiness or have fast development timescales. Agencies and offices that are interested in the state of technologies or technology applications in 5–20 years will focus, in general, on making funding decisions. The long-term forecasters that STPI researchers interviewed said they provide information to external decision-makers to help develop long-term investments, such as infrastructure investments, or long-term organizational strategies. Based on the interviews, STPI researchers grouped the agency forecasting timescales into three bins: (1) short-term forecasting, which looks at technology developments expected in 0–5 years; (2) mid-term forecasting, where the interest is in technology developments expected in 5–20 years; and (3) long-term forecasting, which looks at technology developments expected in 20–30 years.

Desired Capabilities for Automated Forecasting Tools

During interviews, personnel identified both specific tool capabilities that could help with anticipating technology developments and related needs that could potentially be addressed by automated tools. The capabilities that can be addressed by automated tools can be divided into three categories: (1) tracking and summarization capabilities, which give the user information about the current state, contextualized by the past; (2) alert capabilities, which would flag a user if a pre-determined potential future state is likely to occur; and (3) forecasting capabilities, which provide qualitative information about a future state, specifically, within the category of forecasting capabilities, users expressed interest in extrapolation and trend analysis, prediction markets, and the ability to determine the likelihood of a technology having dual-use applications.

The different types of desired capabilities correlate with the short-, mid-, and longer-term timescales into which technology forecasting can be grouped. The tracking and summarization capabilities give information about the present state, prediction markets can support short-term forecasting, extrapolation and trend analysis can support mid- to long-term forecasting, and an alert capability could give information about a particular future state on any of these timescales.

Summary Observations from the Current State of Practice in the Use of Technology Forecasting Tools in the Government

Forecasting activities within the Federal Government vary in terms of the timescales of interest, the desired outcome or information sought, and the level of automation currently used or being pursued. Potential users of automated tools in the Federal Government point to the need for information within the context of their missions and goals. Given the variety of use cases that interviewed personnel described, a single tool or capability is unlikely to meet all the requirements.

Despite the variation in the types of potential applications, a few commonly desired tool capabilities emerged from the interviews: (1) that they present information in an easy-to-visualize way, (2) that they are customizable to a user's specific needs, and (3) that they are trustworthy. Interviewed personnel expressed distrust in the use of automated tools, including technology

forecasting tools. This distrust was expressed by respondents both within and outside the Intelligence Community and the Department of Defense.

Another key finding from the interviews was that capabilities to help understand new or state-of-the-art technology developments in a field (i.e., a summarization and tracking) are seen as a greater need in the decision-making process than a forecasting capability.

The focus on improving awareness of new technology developments (as opposed to information about the future state of a technology) seems to be a result of two factors in combination: (1) analysts getting overwhelmed by the volume of information of which they need to be aware and (2) certain technology development cycles being too fast for analysts to keep up with the technology. As a result, many agencies that are supposed to be aware of emerging technologies are focusing on currently available new technologies rather than future technologies or applications.

Tracking and summarization capabilities could help analysts sort, organize, and distill large amounts of information as well as keep abreast of new developments. Alert capabilities could flag analysts when an indicator passes a pre-determined threshold, notifying them to focus their investigation on a particular issue.

Personnel interviewed overwhelmingly expressed that the role of the human in the loop was critical to the use of forecasting tools in the decision-making process. An output from a tool, according to them, would most likely be further interpreted, contextualized, and explained by analysts prior to being elevated to the level of a decision-maker. Therefore, any tool should therefore be designed to aid rather than supplant the role of the analyst and should not be operated in a stand-alone fashion.

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1. Introduction

The Intelligence Advanced Research Projects Activity (IARPA) funds research on difficult challenges within the Intelligence Community (IC). IARPA has undertaken two science and technology (S&T) forecasting programs: (1) the Foresight and Understanding from Scientific Exposition (FUSE) program, which "seeks to develop automated methods that aid in the systematic, continuous, and comprehensive assessment of technical emergence using publicly available information found in published scientific, technical and patent literature"[1] and (2) the Forecasting Science and Technology (ForeST) program, which seeks to "develop and test methods for generating accurate forecasts for significant [S&T] milestones, by combining the judgements of many experts."[2] To help IARPA improve the development and implementation of its S&T analytical capabilities, IARPA requested that the IDA Science and Technology Policy Institute (STPI) explore the current and potential future use of technology forecasts in S&T decision-making.

A. Goals

The project had two main goals. The first goal was to understand the current state of technology forecasting in Federal agencies in terms of the tools used, the needs supported by those tools, and the role technology forecasting plays in decision-making. The second goal was to understand what technology forecasting capabilities are desired by personnel in Federal agencies in terms of the characteristics of, approaches, and information that agencies would like to use, and the level of tolerance for the uncertainty involved in technology forecasts.

B. Definitions

To scope the findings of the report, it is necessary to define *technology* and *technology forecasting*. Our definition of *technology* is derived from the Department of Defense (DOD) Technology Readiness Assessment and the National Aeronautics and Space Administration (NASA) Technology Readiness Levels (TRLs), which assume a nine-step process of development beginning with basic research and culminating in an operational system. The first step is observation and reporting of basic principles. In the second step,

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1 IARPA website, "Foresight and Understanding from Scientific Exposition (FUSE)," http://www.iarpa.gov/index.php/research-programs/fuse.

2 IARPA website, "Forecasting Science & Technology (ForeST)," http://www.iarpa.gov/index.php/research-programs/forest.

technology concepts or applications are formulated. The third through the sixth steps include experimentation and validation of a technology. The seventh and eighth steps are technology demonstration steps, and the final step is full proof that the technology is able to achieve its mission. The concept of technology forecasting is related to this assumed development pathway, because the idea behind technology forecasting is that advanced technologies have precursors that could be detected and evaluated.

Our definition of *technology* is thus the result of activities ranging from the speculative application of basic principles observed through scientific research to the development of proven systems (Assistant Secretary of Defense for Research and Engineering 2011; Mankins 1995).

We found no single, widely accepted definition for *technology forecasting*. A report on technology forecasting by the National Research Council (NRC) defines it as the "prediction of the invention, timing, characteristics, dimension, performance, or rate of diffusion of a machine, material, technique, or process serving some useful purpose" (NRC 2010). In a report by The Tauri Group, technology development forecasts are described as including "forecasts for the emergence of new technologies, the evolution of existing technology, or the migration of technologies to new application areas…" (Mullins 2012). In an early paper on technology forecasting, J. G. Wissema states that "technology forecasting studies are systematic investigations into the future development and application of technologies. It is not so much that one wants to predict the future but rather one wants to see: which interactions exist with other developments; which actions are possible and what effects they will have" (Wissema 1982). For this report, *technology forecasting* is defined as the prediction of a technology's future characteristics or applications, most often bounded within a particular window of time.

C. Approach

To understand the use of technology forecasting tools and decisions in the Federal Government, STPI research staff conducted interviews with personnel at a range of Federal agencies involved in using information about new or emerging areas of research and technology or new or emerging applications for research and technology.[3] This report does not include interviews with individuals at private sector technology forecasting companies because IARPA's goal is to develop technology forecasting tools for the Federal Government, and therefore is most interested in the views of their potential customers. Interviews were held with personnel within DOD and the IC, as well as within offices involved in other areas of science and technology, such as healthcare, biomedical research,

[3] Although some of the affiliations of the personnel interviewed are departments, offices, or some other entity within the Federal Government, we refer to them all as "Federal agencies" or "agencies" throughout this report.

energy research, and export control. A diverse set of agencies was chosen to explore a range of technology forecasting needs and applications. They are as follows:

- Central Intelligence Agency, Directorate of Science and Technology
- Defense Threat Reduction Agency, Research and Development Directorate
- Department of the Air Force, Air Force Office of Scientific Research
- Department of Commerce, Bureau of Industry and Security, Emerging Technology and Research Advisory Committee and Office of Technology Evaluation
- Department of Defense, Assistant Secretary of Defense for Research and Engineering, Office of Technical Intelligence
- Department of Health and Human Services, Agency for Healthcare Research and Quality
- Department of the Navy, Chief of Naval Operations Strategic Studies Group
- Energy Information Administration
- Government Accountability Office
- National Institutes of Health, National Institute of Biomedical Imaging and Bioengineering
- Office of the Director of National Intelligence, Acquisition, Technology, and Facilities

Appendix A provides the interview method and guide. The information from these interviews (summarized in Appendix B) was supplemented with additional research and case studies.

D. Report Overview

The structure of this report is as follows:

- In Chapter 2, we discuss the current use of technology forecasting in the Federal Government, including triggers that initiate technology forecasts, forecasting timescales that different agencies examine, current and potential use of technology forecasts in decision-making, and current levels of automation in technology forecasting. We also discuss the issue of trust in forecasting tools.
- In Chapter 3, we discuss the capabilities that the personnel we interviewed currently do not have but would like to have.
- In Chapter 4, we discuss the implications of our findings for IARPA's technology forecasting efforts and provide recommendations.

- Appendix A contains the interview methodology and guide; Appendix B contains summaries of the interviews; Appendix C contains descriptions of some of the analytical and forecasting tools, techniques, and other aids discussed in the report; and Appendix D provides case studies of agencies that could potentially use technology forecasting tools to support their different missions.

2. Current State of Technology Forecasting in the Federal Government

During interviews, respondents were not presented with a definition of *technology forecasting* because part of the goal of the interviews was to understand the respondents' own perceptions and understanding of the term. Respondents were informed that the goal of the project was to understand current and potential roles of technology forecasting and technology forecasting tools in decision-making processes in the Federal Government, and then they were asked whether they currently use technology forecasting or projections.

Respondents seemed to be comfortable speaking about technology forecasting despite not being given a definition. The majority of respondents viewed awareness about potential future directions of research and technology to be a part of their jobs. In addition to speaking about technology forecasting, they often spoke about tracking people or events. Respondents frequently spoke about science and technology analytics that are distinct from forecasting. The interviews revealed that technology forecasting is relevant for a range of mission-specific goals, including:

- Gathering intelligence;
- Identifying threats and opportunities emerging from potential future applications of technologies (e.g., public health threats and dual-use technology applications);
- Managing research portfolios,
- Understanding how future scenarios might be shaped or affected by today's long-term technology investments, and
- Understanding economic and policy implications of the evolution and global availability of commercial technologies or products.

Table 2 summarizes the relationships that the interviewed personnel have to technology forecasting at their agencies.

Table 2. Interview Respondents' Agency Affiliation, Goal, and Relationship to Technology Forecasting

Respondents' Agency Affiliation	Agency Goal	Agency Relationship to Technology Forecasting
Central Intelligence Agency (CIA), Directorate of Science and Technology (DS&T)	DS&T researches, develops, and applies advanced technologies that provide the national with a significant intelligence advantage[a]	DS&T needs to be aware of new technologies that will help to maintain a significant intelligence advantage
Department of the Air Force, Air Force Office of Scientific Research (AFOSR)	AFOSR funds research that supports the Air Force goals of control and maximum utilization of air, space, and cyberspace[b]	AFOSR needs to be aware of emerging areas of research
Department of Commerce (DOC), Bureau of Industry and Security (BIS) Emerging Technology and Research Advisory Committee (ETRAC) and Office of Technology Evaluation (OTE)	BIS determines export controls needed for "dual-use" technologies, or technologies that have both civil application and applications related to the military, terrorism, or weapons of mass destruction[c]	BIS identifies emerging dual-use technologies
Department of Defense (DOD), Assistant Secretary of Defense for Research and Engineering (ASD[R&E]), Office of Technical Intelligence (OTI)	OTI analyzes global science and technology (S&T) activities to inform research investments[d]	OTI conducts technology watch and horizon scanning activities. They are also pursuing automated approaches for these activities[d]
Department of Health and Human Services (HHS), Agency for Healthcare Research and Quality (AHRQ)	AHRQ informs patient-centered outcomes research investments[e]	AHRQ has developed the Healthcare Horizon Scanning System, which scans emerging healthcare technologies
Department of the Navy, Chief of Naval Operations (CNO), Strategic Studies Group (SSG)	CNO SSG generates revolutionary naval warfare concepts [f]	CNO SSG needs to be aware of future technologies and their implications for the Navy
Defense Threat Reduction Agency (DTRA), Research and Development Directorate (J9)	DTRA J9 funds and conducts research and development for threat reduction[g]	DTRA J9 needs to be aware of new technologies to tackle existing threats and needs to be prepared for emerging and future threats
Energy Information Administration (EIA)	EIA produces short-term forecasts and long-term projections of energy sources, end uses, and energy flows[h]	EIA models energy and economic trends

Respondents' Agency Affiliation	Agency Goal	Agency Relationship to Technology Forecasting
Government Accountability Office (GAO)	GAO prepares technology assessments of current and emerging technologies to understand implications, challenges and opportunities for the Federal Government and their potential societal impacts.[i]	GAO needs to be aware of the societal implications of current and emerging technologies
National Institutes of Health (NIH), National Institute of Biomedical Imaging and Bioengineering (NIBIB)	NIBIB funds the research and development of new biomedical imaging and bioengineering techniques and devices to improve disease detection, prevention and treatment.[j]	NIBIB needs to be aware of new and emerging areas of research and technology in this field
Office of the Director of National Intelligence (ODNI), Acquisition, Technology, and Facilities (ATF)	ATF informs research and development investments to solve current and future intelligence challenges.[k]	ATF needs be aware of emerging science and technology and the potential future capabilities that they could offer for the intelligence community.

[a] CIA Science and Technology Office Website, "Who We Are," https://www.cia.gov/offices-of-cia/science-technology/who-are-we.html.

[b] AFOSR website, "About—Mission," http://www.wpafb.af.mil/library/factsheets/factsheet.asp?id=9492.

[c] Emerging Technology and Research Technical Advisory Committee website, "U.S. Department of Commerce Charter of the Emerging Technology and Research Advisory Committee," http://www.bis.doc.gov/index.php/licensing/28-technology-evaluation/147-emerging-technology-and-research-technical-advisory-committee.

[d] Department of Defense Research & Engineering Enterprise website, "Science & Technology Corner, Technology Watch and Horizon Scanning for the Department of Defense," http://www.acq.osd.mil/chieftechnologist/cto/cto_TWHS.html.

[e] AHRQ, Effective Health Care Program website, "AHRQ Healthcare Horizon Scanning System," http://effectivehealthcare.ahrq.gov/index.cfm/who-is-involved-in-the-effective-health-care-program1/ahrq-horizon-scanning-system/.

[f] CNO SSG website, "Overview—About," https://usnwc.edu/About/Chief-Naval-Operations-Strategic-Studies-Group.aspx.

[g] DTRA website, "Research & Development," http://www.dtra.mil/Research.aspx.

[h] EIA website, "About EIA—Mission and Overview," http://www.eia.gov/about/mission_overview.cfm.

[i] "Technology Assessment" URL: http://www.gao.gov/technology_assessment/key_reports.

[j] "National Institute of Biomedical Imaging and Bioengineering (NIBIB)—Mission," http://www.nih.gov/about-nih/what-we-do/nih-almanac/national-institute-biomedical-imaging-bioengineering-nibib.

[k] ODNI website, "Acquisition, Technology, & Facilities—What We Do," http://www.odni.gov/index.php/about/organization/acquisition-technology-and-facilities-what-we-do.

To fully explore this chapter's topic of the current state of technology forecasting, we discuss triggers that initiate or prompt technology forecasting activities; different applications of technology forecasting, which can be divided into the timescales for which the forecasts are desired; the decision-making structures in which forecasts are used; the variation in the amount and type of automation in forecasting; and issues of trust surrounding the use of automated forecasts.

A. Triggers that Initiate Technology Forecasting

Two general models describe when an investigation of a new or emerging technology or application is initiated. The first model is when the need for a technology or application is initiated by routine surveillance and reporting requirements. Some technology forecasts are made periodically because of an agency's mission. Examples include the *Annual Energy Outlook* produced by the Energy Information Administration (EIA), and the Potential High Impact Reports produced by the Agency for Healthcare Research and Quality (AHRQ). These reports are updated frequently (yearly for the *Annual Energy Outlook* and every 6 months for the Potential High Impact Reports), and the updates are independent of any particular event occurring.

The second model is a reactive model in that a technology or application is examined to understand the potential impact of a specific event occurring or need arising. A basic research development, a new commercial product, or a dramatic decrease in cost for a technology could trigger an investigation into the current and anticipated state of a technology or a technology-influenced event to determine the various impacts of these developments. Another trigger could be the acquisition of companies by other companies, whether it is a single company buying many smaller companies or companies in one country purchasing many companies of a particular industry in another country. These two models (routine surveillance versus a reaction) are similar to what is referred to as a police-patrol model versus a fire-alarm model in the context of congressional oversight (McCubbins and Schwartz 1984).

B. Technology Forecasting Applied to Decision-Making at Different Timescales

Based on their function and goals, agencies of the Federal Government may be interested in understanding developments at different points in a technology's evolution. For example, defense acquisition programs makes technology investments in the 20–30-years before the expected delivery of a platform. These agencies are interested in understanding basic research areas or very early stage technologies whose desired applications are anticipated to be developed for military use in the 20–30-year time frame.

On the other hand, agencies that align more closely with a reactive agenda, such as the Department of Commerce (DOC) Bureau of Industry and Security (BIS), which makes

decisions on export controls, and the Defense Threat Reduction Agency (DTRA) Research and Development Directorate (J9), whose goal is to identify threats associated with a new or unanticipated use of a technology, are more interested in understanding technologies that have reached (or are close to) the application stage, and may be used in ways that have an impact on national security. These agencies are interested in understanding research developments or commercially available technologies that may arise in the 0–5-year time frame.

The more long-term the investment, the greater the need to look upstream of the technology development process and track any changes therein; agencies that are interested in technologies when they are much closer to the point of application could incorporate data such as market reports, healthcare trends, or product specifications, as input into their technology forecasting process. Accordingly, the agencies with which the personnel interviewed were affiliated are grouped by their forecasting timescale, and divided into three bins: short-term (0–5 years in the future), mid-term (5–20 years in the future), and long-term (20–30 years in the future). The timescale bins do not specify whether a technology is in research phase, proof-of-concept phase, emergent, or widely available. This is because the timescale bins reflect the time horizon over which an agency is concerned, not the amount of time with respect to a technology reaching a certain point in its development. Depending on its mission, an agency may be concerned with any state of technology development. The forecasting efforts within each timescale bin could be further categorized as to whether or not the agency is using or pursuing any automated methods for their forecasts. The different levels of automation are discussed in section C of this chapter.

1. Short-Term Forecasting (0–5 years)

In general, the agencies that are interested in the state of technologies or technology applications that are within 0–5 years of being realized are preparing to respond quickly to technologies that have already reached the later stages of technology readiness. For example, the Bureau of Industry and Security (BIS) examines technologies that are ready for commercialization in order to determine whether their export should be controlled. The Government Accountability Office (GAO) examines and briefs Congress on emerging technologies and their potential implications. AHRQ examines procedures, medications, and other factors that are 1 to 2 years away from Food and Drug Administration (FDA) approval in order to provide information about healthcare coverage. DTRA J9 initiates research efforts in response to emerging threats. The Central Intelligence Agency (CIA) Directorate of Science and Technology examines technologies for science and technology intelligence purposes. The directorate's forecasting efforts look at technologies that can be acquired within 3 years, which corresponds to their acquisition cycle.

Is It Short-Term Forecasting or Is It "Nowcasting?"

In many interviews, respondents were concerned about being able to "keep up" with new technologies or applications in their fields. Interview respondents were more interested in capabilities to help them understand new or state-of-the-art technology developments in their field (i.e., a summarization capability that improves their situational awareness) than provide information about a future state of a technology or research area (i.e., a forecasting capability). For the purposes of this report, we consider these respondents' agencies and offices to be interested in short-term forecasting because the decisions they are trying to make focus on preparedness for a future state. Such a summarization capability is seen as a greater need than a forecasting capability in the decision-making process.

Because 0–5-year technology forecasts appear to support fields that are rapidly changing and fields that need to be aware of later-stage technology developments, it is possible to use these criteria to identify additional agencies that could use short-term forecasts.[4] For those agencies that are interested in late-stage technology development, information summarization and horizon scanning tools could help since strong indicators of the technology should already be present. For the agencies that are interested in rapidly changing fields, any tool would have to be able to take in new information frequently enough to provide useful insights on likely future developments.

[4] Because the timescale of cyberthreat and software development is frequently less than 5 years, cyber-related decision-makers would likely also be concerned with forecasting within this short timescale. Similarly, the FDA regulates and supervises many factors related to public health and would likely also want to be aware of new drugs, technologies, and treatments that are nearing the stage where testing and regulation will be necessary.

2. Mid-Term Forecasting (5–20 years)

Among the set of agencies interviewed, the agencies that are interested in technology developments or applications that are expected to come to fruition in 5–20 years are making funding decisions. Each of the scientific funding agencies in which interviews were conducted—the Air Force Office of Scientific Research (AFOSR), the Office of Technical Intelligence (OTI) in the Office of ASD(R&E), DTRA J9, and the National Institute of Biomedical Imaging and Bioengineering (NIBIB)—make decisions about what research to fund based on where they envision a field of research being in 5–20 years.

> **Tracking Researchers**
>
> A capability to identify researcher networks and track young scientist collaborations could be used to identify potential areas of research and researchers to fund. One respondent pointed out that traditional metrics, such as number of publications or H-index, which are used to evaluate principal investigators do not necessarily apply to young investigators. A tool that is able to predict which young investigators are likely to advance the field could help program managers decide which young investigators to fund.

Funding decisions take different forms and can occur at different levels in the Federal Government. Each of the program managers interviewed make choices about which principal investigators and which projects to fund within a research area; higher level managers can make decisions about which research directions should be pursued; and both agency leadership and Congress make large-scale decisions about new areas of research to fund and areas of research funding that should be redirected or discontinued.

Funding decisions are informed by the decision-maker's knowledge of the field of research, the mission and needs of the relevant agency, and the decision-maker's knowledge of the agency's needs. Technology forecasts could therefore be used to ensure that decisions are made based on (1) the best available information and (2) the agency's mission and needs. Both of these needs are discussed in more detail below.

Program managers may not be aware of all the relevant information necessary to make the best funding decision. The large volume of relevant literature, product releases, patents, and other written material, coupled with the prohibitive costs of attending conferences means that program managers are probably going to see only a subset of literature and attend only a subset of conferences. Consequently, a program manager may be inadvertently biased by the limited information to which he or she is exposed. A tool that ingests a varied and updated set of scientific publications and conference abstracts; identifies trends; and predicts which areas of research may soon grow in popularity, change directions, or intersect with another area of research could address this problem.

As mentioned previously, technology requirements—such as DOD's acquisition requirements—are sometimes written for programs that span a time frame of 10–20 years. The platform in question may require capabilities that are still in development at the time that the requirements are being written. A useful tool from the perspective of acquisition officials would be one that first uses subject matter experts to break down a desired future technology to its enabling capabilities, and then uses an automated approach to find publications that either mention these capabilities or connect in some way with research towards these capabilities. Such a tool could help a program manager identify where investments should be made in areas of research or researchers.

Based on the findings about the decision-making structures (discussed in detail in Chapter 3), automated capabilities of the types mentioned above would likely be used by program managers to identify and propose new research directions, which could then be communicated to agency leadership or Congress. There may be other customers of mid-term technology forecasts, though with the exception of EIA, all of the respondents concerned with mid-term forecasts worked at funding agencies.

Forecasting versus Prediction versus Projection

In some communities, such as the climate research community, the term *forecast* (which is used interchangeably with the term *prediction*), is distinguished from the term *projection*. A forecast or prediction depends on the initial conditions, whereas a projection depends on initial conditions and additional assumptions that influence the future state (Intergovernmental Panel on Climate Change, "Glossary of Terms used in the IPCC Fourth Assessment Report," Working Group I). Because projections tend to be for a longer time scale than forecasts or predictions, additional assumptions need to be made, so the projections tend to have higher levels of uncertainty. However, in this report, the terms *long-term forecasts* and *projections* are used interchangeably.

3. Long-Term Forecasting (20–30 years)

The EIA makes forecasts for 20–30-year timescales. While information about an energy technology's development may be used to develop its model, EIA's goal is not to forecast technology, but to forecast energy sources, end-uses, and energy flows. EIA provides information to external decision-makers to help develop long-term investment or organizational strategies. Because these forecasts are helpful for making long-term infrastructure investments, additional agencies that make similar large-scale, long-term investments, such as the Department of Defense, Department of Transportation, the Department of Energy, and NASA, may also be interested in long-term forecasting.

Because of their long timescales, these forecasts have significant levels of associated uncertainty. It could be useful for decision-makers to know what technology outcomes may come to fruition at a certain point in the future, given a certain set of assumptions. Trend analysis tools could help long-term forecasters by allowing them to select different

parameters, such as speed of development or different manufacturing cost curves, and examine how those different parameters impact a technology's diffusion or cost.

Another factor associated with long timescales of technology development is that the terminology associated with a research area or technology may change over its life cycle. It is even possible for the name of a technology or terms associated with it to disappear from literature as it moves through different stages of development. Approaches and tools for tracking changes in terminology would be helpful to users who track technology over a long period of time.

C. Decision-Making Structures

STPI researchers were asked to examine how technology forecasting tools are currently used, or could be used, in the decision-making process. In particular, IARPA expressed interest in knowing whether information from technology forecasts directly determine a decision, or whether forecasts are used as a source of background information.

In discussing how technology forecasts are used or could be used in the Federal Government, the interviews revealed a small set of decision-making structures and roles. STPI research staff did not encounter any cases in which the decision-maker is the same person who interacts closely with a technology forecasting tool. The simplest structure included two roles: (1) someone who collects data, creates or uses a forecast, and analyzes it and (2) the decision-maker. In more complicated structures, the role of the analyst is separated from that of the data collector or forecast user, creating three roles: (1) someone who collects data and creates or uses a forecast, (2) an analyst, and (3) a decision-maker. In more elaborate structures, there are multiple levels of decision-makers. As an example, a team could include (1) someone who collects data and creates or uses a forecast, (2) an analyst, (3) a lower level decision-maker, and (4) a higher level decision-maker. In each of the steps following the technology forecast step, additional information may be brought in to be used in combination with the technology forecast to enable a decision. These decision-making structures are shown in Figure 1.

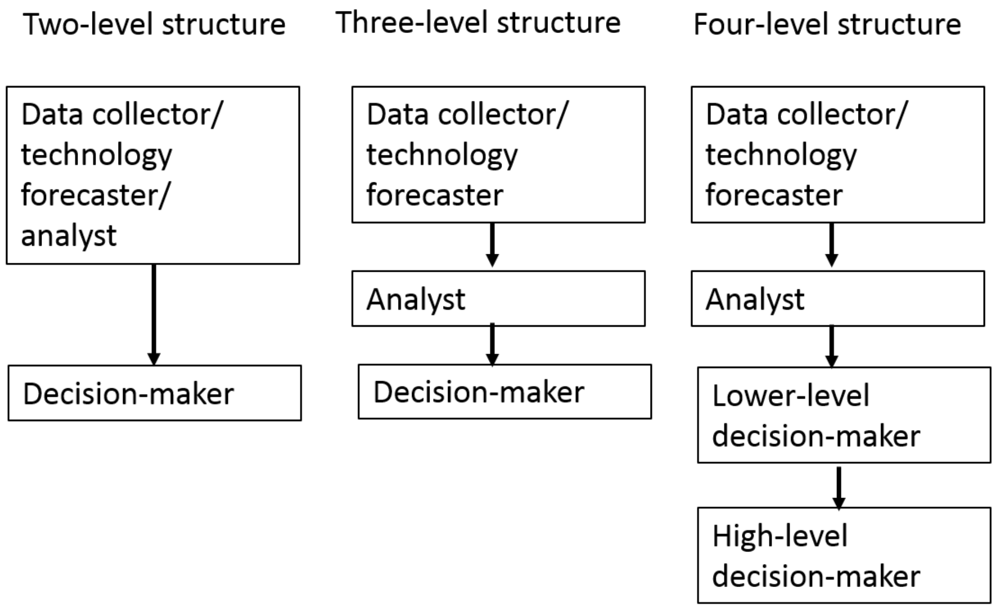

Figure 1. Decision-Making Structures for Technology Forecasting

The data collected may come in the form of a tool output, a curated data set, or information from subject matter experts (SMEs). SMEs were encountered in many of the decision-making structures and in all of the different forecasting timescales. SMEs could act either as primary data sources, or as support to analysts by providing additional expertise or context. The role of SMEs ranged from providing occasional advice to being a part of a structured process, which was the case at AHRQ (discussed further in Appendix D).

The decision-makers that were discussed in interviews included program managers, mid-level managers, and agency leadership. In many cases, the decision-makers were external to the agency. External decision-makers may include members of Congress, the general public, and the private sector. For example, the EIA produces the Annual Energy Outlook, which examines how various scenarios might impact the energy market in the coming decades. (*Annual Energy Outlook 2015* projects out until 2040.) EIA makes decisions regarding how to build the models and scenarios. Based on the results of the projections, investors may decide to invest in different energy sources, members of Congress may use the projections to inform policies, and energy suppliers may make plans for infrastructure changes. Even when the decision-makers are in the same agency where the forecast is produced, the interview respondents indicated that technology forecasting is viewed as a way to maintain awareness rather than as a specific input into a decision.

D. Levels of Automation in Technology Forecasting

Most Federal efforts to forecast new and emerging technologies and applications are completely unautomated. Automated efforts tend to be focused on methods that extract information on the current state of technology from vast amounts of data, but do not have a predictive element. In this section, we discuss the different levels and approaches that interview respondents said they are taking to automate forecasting.

1. Agencies that Use Automated Methods

Only two of the agencies at which we conducted interviews currently use automated tools, and only one of those agencies uses automated methods for forecasting (though it is not technology forecasting). The EIA prepares forecasts of energy demands by technology and by sector. The forecasts are based on the National Energy Modeling System (NEMS), which is an integrated model of the U.S. energy demands developed internally at EIA. NEMS "projects the production, imports, conversion, consumption, and prices of energy, subject to assumptions on macroeconomic and financial factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, cost and performance characteristics of energy technologies, and demographics" (Energy Information Administration 2009). NEMS has been used to examine the impacts of existing or potential energy policies, as well as new energy technologies. To develop accurate forecasts, NEMS includes models for how technologies improve over time. For certain energy sectors, EIA considers individual technology characteristics, including the "initial capital cost, operating cost, date of availability, [and] efficiency" (Energy Information Administration 2009). To model this data well, EIA's modelers should be aware of the state of the art of each technology and its likely trajectory for improvement. However, this information is only used as an input to the model; the model itself does not produce a technology forecasting.

The Directorate of Science and Technology at the Central Intelligence Agency leverages commercial tools for data analytics. They have ongoing funded efforts exploring emerging analytics technologies for forecasting. Respondents at the Office of the Director of National Intelligence Office of Acquisition similarly indicated having used commercial tools to watch new and emerging technologies, though they do not use any automated tools for technology forecasting.

2. Agencies Currently Pursuing Automated Methods

Most of the agencies that are currently pursuing automated technology forecasting methods fund scientific research and make mid-term forecasts. Currently, automated tool use focuses on gap analysis and understanding the current state of the field, and is not predictive. However, there is interest in moving towards predictive technologies.

At NIBIB, technology assessments are conducted as part of their portfolio analysis work. The goal is to understand and address funding gaps. The gap analysis is conducted using IN-SPIRE (discussed in more detail in Appendix C) and bibliometric analysis tools; once potential areas are identified, expert input is sought to determine research areas that NIBIB should fund in the future. Interview respondents at NIBIB expressed interest in tools that would assist in other aspects of portfolio analysis, such as peer review, allocation of funds and understanding how collaborations and grants come together. The ultimate goal is to be able to make better decisions about what research should be funded.

AFOSR currently uses scientometric analysis and large-scale data analysis for portfolio analysis and understanding trends in basic science research areas. These data analytics tools come, in part, from the Basic Research Innovation Collaboration Center (BRICC), with which AFOSR is collaborating.[5] The respondents at AFOSR indicated that they do not currently employ any approaches for predictive analysis, whether automated or manual. However, they have investigated the use of FUSE to identify emerging areas of research, and previously assessed the basic areas of research needed to support the long-term technical capabilities needed by the United States Air Force.[6]

DTRA J9's goal is to anticipate emerging threats arising from technologies associated with chemical, radiological, biological, and nuclear weapons of mass destruction. While the respondents at DTRA J9 would like to use a predictive tool or system, currently their effort is based on an assessment of observable trends, which are reviewed by subject matter experts within the Countering Weapons of Mass Destruction (CWMD) community of practice. Respondents at DTRA J9 indicated that their current methodology is based on anecdotal evidence and is not rigorous; they would like to explore the use of an automated tool that is analytically driven.

OTI within the Office of the ASD(R&E) leverages commercial technology forecasting systems and invests in the development of new forecasting approaches that integrate multiple data analysis streams and a suite of science and technology forecasting tools (including a technology watch and a horizon scanning tool, which are discussed further in Appendix C). Currently, the OTI tool uses data analytics, but is not predictive. However, the goals of the technology watch and horizon scanning tool involve forecasting, since they are to "identify emerging S&T areas that will enhance operational capability in the next 10–20 years, assess scientific areas that should be included in the long-range (10+ years) research strategy, and provide context to understand the S&T that will result in

5 BRICC website, "BRICC Projects," http://bricc.vt-arc.org/.

6 Forthcoming report from the IDA Science and Technology Policy Institute.

significant new discoveries."[7] The respondents at OTI said that they were interested in developing or using a predictive forecasting capability; however, they view their role as integrating rather than developing advanced forecasting tools, and they would need agencies like IARPA to develop those tools. OTI respondents further mentioned that, even with an automated system, they envision having subject matter experts involved to refine the tool output.

3. Agencies Not Pursuing Automated Processes

Personnel at the three agencies that are not pursuing automated processes each focus on short-term technology forecasting, in which the technologies are already in late development stages, and the role of the office is principally to understand the potential implications of the application of these technologies in the short term. These agencies also base their projections on a wide variety of inputs in addition to scientific literature, thereby capturing not only the technology aspects but also market factors and economic and national security impacts.

Respondents were unfamiliar with publicly available automated tools and seemed to have neither the time nor the staffing resources to pursue new methods. Despite their not having automated tools, their technology assessment and forecasting processes may be complex.

BIS in DOC tracks the evolution of potential dual-use emerging technologies and determines whether their export should be regulated. (This is discussed in more detail in Appendix D.) A committee of technical experts identify candidate technologies for export control regulation. In this process, a factors are examined that range from the stage of technology development, to the impact of global sales of the technology, to the effect on industry of restricting sales. The process is geared towards looking at technologies in late stages of development, and the analysis focuses on how export of these technologies could trigger a situation of national security concern in the future.

GAO's technology assessments look at the anticipated trajectory of emerging technologies, cost factors, and economic and policy implications. The manual process relies on literature reviews by librarians and consultations with subject matter experts. The respondents at GAO expressed that one of their most significant challenges is forecasting the global economic impact of technologies, and they said that they would benefit from the use of a tool or methodology to identify historical patterns that have shaped the trajectory of general purpose technologies, and apply the insights to their studies.

[7] Department of Defense Research & Engineering Enterprise website, "Science & Technology Corner, Technology Watch and Horizon Scanning for the Department of Defense," http://www.acq.osd.mil/chieftechnologist/cto/cto_TWHS.html.

AHRQ within the Department of Health and Human Services has the most structured non-automated technology forecasting system that was encountered during the interviews. AHRQ has developed a horizon scanning system called the Healthcare Horizon Scanning System, a 10-step process for identifying emerging technologies and healthcare innovations. This system is discussed in more detail as a case study in Appendix D. In the Healthcare Horizon Scanning System, medical librarians scan publicly available sources such as medical journals, scientific literature, company press releases, trade publications, and newsletters for leads. Analysts and topical experts review and analyze all leads in a process combining validation and in-depth research. The final output is used to inform healthcare companies and the general public on potentially high-impact healthcare products and trends. This method involves examining the future implications of a healthcare innovation if it becomes publicly actionable, rather than forecasting future technologies.

E. Trust

Trust emerged as a key topic during interview discussions of the current state of technology forecasting. Responses varied from the extreme trust in and preference for an automated tool, with respondents viewing such tools as agnostic to human prejudice, to complete distrust of anything other than an SME who is familiar to the respondent. According to respondents both within and outside the IC and DOD, this distrust extends to other types of automated tools, not just those used for forecasting.

Almost all respondents relied heavily on SMEs for their interpretations of the future of technology; many relied entirely on SMEs. Trust in human judgement over data or models was the general justification for this. Many respondents also reported that even if technology forecasts were used, especially computer-generated models, they would, at most, be used to verify or support the opinions of trusted SMEs.

Much of the reliance on SMEs appeared to be the result of the role of analysts within the larger Federal Government structure and the interaction between analysts and their bosses—the decision-maker. Reasons cited for including the opinions of SMEs in the information chain included accountability of the analyst to the decision-maker, potential distrust of the decision-maker, and concern about what might be done with information if it were divorced from analyst-provided context. One respondent noted that computer models cannot be questioned or held accountable for bad decisions or incorrect forecasts in the same way that a human could be.

F. Discussion of the Current State of Technology Forecasting in the Federal Government and its Implications for Future Forecasting Tools

The landscape of technology forecasting efforts in the Federal Government shows a substantial amount of variation. Agencies are interested in forecasting timescales ranging from under 5 years in the future to 30 years in the future. They are also in different stages in terms of their pursuit of automation for forecasting. Table 1 summarizes the timescale and automation bins in which each agency belongs. Note that some agencies belong in multiple bins, or they currently reside in one bin, but have the goal of progressing to a different bin.

The technology forecasting activities of most agencies are specific to the mission of the particular agency. This is true, even when the agency is interested in horizon scanning activities. The "area of interest" of the horizon may be as specific as a single program manager's portfolio. Sometimes, an agency does not get to define with technologies it examines. In the case of GAO and the BIS Office of Technology Evaluation, the technologies to be examined are assigned for investigation. In these cases, in which a technology is in late stages of development, the focus of the forecasting effort is on the downstream implications of the technology.

Table 1. Agencies Grouped by Their Forecasting Timescale, and Whether They Currently Are Using, Pursuing, or Not Pursuing Automated Methods

	Forecasting Timescale		
	Short-term (1–5 years)	**Mid-term (5–20 years)**	**Long-term (20–30 years)**
Using Automated Methods	CIA, EIA*	EIA*	EIA*
Pursuing Automated Methods	DTRA J9 (currently)	AFOSR, DTRA J9 (goal), DOD OTI (ASD[R&E]), NIBIB	
Neither Using nor Pursuing Automated Methods	AHRQ, BIS, GAO		

* While EIA produces forecasts on these timescales, they are not technology forecasts.

Some agencies have not explored automation at all, even when commercial or free resources are available to streamline their process. In contrast, EIA uses the National Energy Modeling System to do sophisticated modeling that integrates economic, technological, and demographic data.

At multiple agencies that make decisions based on anticipated technology developments, the focus is on improving awareness of the current state of research and new

technology developments rather than future technologies or applications. This seems to be due to a combination of two factors: (1) analysts are overwhelmed by the volume of information that they need to be aware of, (2) technology development cycles may be too fast for analysts to keep up with the technology.

Tools could potentially help address both of these problems. In the case of analysts being overwhelmed with information, tools could help integrate, summarize, and highlight key pieces of information. In the case of fast technology development cycles, tools could be used to constantly scan the horizon for indicators to keep analysts abreast of new developments.

Given both the decision-making structure in the government and the significant role of analysts in contextualizing information for decision-making, it is likely that any technology forecasting tools or their outputs produced in the near-term would be used by analysts or program managers, and not by higher level decision-makers. The managerial structure also means that if a technology forecast is used by analysts or program managers, the forecast would likely be one of multiple inputs into a decision, rather than a single input to a decision.

In general, respondents reported a willingness to use automated tools but only with a high level of data verification and an understanding of data inputs. Respondents overwhelmingly felt that the role of the human in the loop was critical to the use of forecasting tools in the decision-making process. An output from a tool, according to respondents, would most likely then be further interpreted, contextualized, and explained by analysts prior to being elevated to the level of a decision-maker. Therefore, any tool should be designed to aid rather than to supplant the role of the analyst, and it should not be operated in a stand-alone fashion. In the following chapter, the specific capabilities of automated tools that could provide support to analysts are discussed.

3. Desired Capabilities of Automated Tools

During interviews, respondents identified specific capabilities that could help them with their forecasting work as well as general needs that could potentially be addressed by automated tools. Some of the automated tools that could help would not necessarily be considered technology forecasting tools, since they would not be predictive. This chapter distills the different capabilities that could be useful to the personnel interviewed and to others in the Federal Government with similar needs. The capabilities are divided into three categories: (1) forecasting capabilities, which provide qualitative information about a future state, (2) alert capabilities, which would flag a user if a pre-determined potential future state is likely to occur, and (3) tracking and summarization capabilities, which give the user information about the current state, contextualized by the past. The goals of each of these capabilities and the relationships to a potential future state are shown in Table 3.

Table 3. Categories of Capabilities Desired by Interview Respondents

Capability	Goal	Relationship to a Potential Future State
Forecasting	Provide qualitative information about a future state	Predicts a future state
Alert	Notify users that a pre-determined potential future state is likely to occur (with a pre-specified level of probability)	Pre-determined indicators relate to a specific future state
Tracking and Summarization	Provide information about the current state	Provides no information about any potential future state

While multiple agencies may find one or more of the capabilities discussed here useful, the application of that capability would likely depend on each agency’s mission. Consequently, the “user requirements” for a given capability at different agencies would likely vary.

A. Forecasting Capabilities

Relatively few interview respondents expressed interest in a capability that would provide the user with qualitative information about a future state. The respondents that did express an interest would be interested in capabilities that identify trends in current

technology and provide a basis for predicting the future characteristics of a technology and the future applications of a technology. These capabilities are discussed in more detail below.

1. Extrapolation and Trend Analysis

In extrapolation and trend analysis, a user or tool uses information from the past and present to forecast a future state. These techniques assume, according to the National Research Council (NRC) study, *Persistent Forecasting of Disruptive Technology*, that "the future represents a logical extension of the past and that predictions can be made by identifying and extrapolating the appropriate trends from the available data" (NRC 2010). This suggests that trend extrapolation and analysis work can work well if the historical forces that drive the trend remain the same, but can fail if those forces change (NRC 2010). The NRC study presents four different types of extrapolation and trend analysis: (1) trend extrapolation, in which recent technology trends are projected into the future; (2) Gompertz and Fisher-Pry substitution analysis, in which a technology's evolution is assumed to be an "S-shaped" growth curve as it is developed, deployed, and reaches maturity; (3) analogies, in which information about specific previous technologies and situations are used to examine the evolution of a current technology; and (4) morphological analysis, which is a structured process that applies general information about technology evolution to examine how a new technology could evolve.

Trend extrapolation was mentioned as a capability of interest by interview respondents at DTRA J9. The appeal of trends is that they are closely tied to observable information and they could be presented to analysts for interpretation. Respondents at GAO also expressed interest in trend extrapolation, as well as in analogies. The respondents said that they would like to have a tool that can identify historical patterns for general purpose technologies and apply those trends and patterns to assess new technologies to examine the direction that they will take. Morphological analysis, which uses principles of technology evolution rather than specific examples of relevant technology evolution, could also potentially be useful to GAO, since the respondents expressed interest in understanding the factors that enable technology development. While not mentioned by EIA respondents, substitution analysis could potentially be helpful with predicting the costs and diffusion of specific energy technologies in the NEMS models.

Extrapolation and trend analysis tools would likely be most useful for agencies that are focused on forecasting technologies in middle to late development stages. For agencies attempting to make forecasts about technologies or applications 20–30 years in the future, there may not be enough data to establish a trend since the technology would only be in early development stages, with little evidence of its development pathway. Similarly, for agencies that focus on technologies with fast development cycles, there may not be enough time to establish a clear trend before the technology reaches maturity.

2. Dual-Use Probability Calculation

A variation on the ability to forecast the future state of a technology by extrapolating historical trend data is the ability to project possible trajectories for a technology given varying sets of driving forces. One of the particular applications of interest would be a tool that is able to determine the probability of a technology at an early development stage becoming a dual-use technology.

At early technology development stages, the different trajectories that a given technology could take may result in a range of potential future characteristics and applications. While predicting the exact form of applications that will dominate in the future is difficult at best, it is possible to make a "range of forecasts" of performance characteristics and applications in the future by considering the factors that shape the development and adoption of a given technology in its different applications. By determining which final states have military and civil applications, and the likelihood of these states occurring, it could be possible to determine the likelihood that a technology becomes dual use.

A dual-use capability could be used by DTRA J9 and BIS in DOC. DTRA J9's goal is to anticipate emerging threats related to weapons of mass destruction and provide timely responses. While DTRA J9 is made aware of recent and emerging threats (corresponding to technologies in late development stages), if they were able to determine the likelihood that an early stage technology could become a threat, they would have greater lead time to respond. Currently, DTRA J9 manually collects information on trends, assesses the trends, and has the assessments analyzed by DTRA and the CWMD community of practice to identify implications for weapons of mass destruction. This process is seen by the respondents as lacking analytical rigor and largely based on anecdotal knowledge and evidence; the respondents at DTRA J9 therefore expressed interest in institutionalizing a technology forecasting capability aimed at identifying emerging threats. While the office is currently exploring automated trend analysis, a tool that is able to calculate a dual-use threat could be added to this capability to select which technologies should be further investigated by analysts. The BIS OTE, which assesses new technologies and their potential for dual-use applications, could also benefit from such a tool. Currently, potential dual-use technologies are selected by external groups, such as the Emerging Technology and Research Advisory Committee, and then given to OTE to conduct in-depth analysis. A dual-use calculation tool could help ensure that OTE is examining the technologies with high probabilities of becoming dual use. Such a tool would also be helpful throughout the IC and DOD.

3. Prediction Markets

In prediction markets, the collective judgement of a group of individuals is used to generate forecasts about an event or parameter. Predictions are treated "as assets to be

traded on a virtual market that can be accessed by a number of individuals…. The final market value of the asset is taken to be indicative of its likelihood of occurring” (NRC 2010). As an example, to understand the probability of a candidate winning an election, participants would say whether or not they think that the candidate will win the election. Incentives can be set up such that the participant must pay to make a prediction and receives a payout depending on the outcome of the event (Wolfers and Zitzewitz 2004), or such that participants are rewarded for participation or accuracy (George Mason University 2015). The principle behind using a prediction market approach is that the aggregation of a set of judgements generally generates more accurate forecasts than individual experts (George Mason University 2015). SciCast, a prediction market project funded by IARPA and developed by George Mason University, is briefly summarized in Appendix C.

Two respondents, one from AHRQ and one from NIBIB, expressed interest in crowdsourced tools related to prediction markets. Currently, AHRQ has a non-automated operational forecast system called the Healthcare Horizon Scanning System to identify innovations that could meet previously unmet health needs. (This system is discussed in more detail in Appendix D.) A crowdsourced prediction system could allow participants to suggest additional innovations, as well as to make predictions related to innovations. According to the respondent, NIBIB has explored posing research challenges to the general public and receiving feedback, and the respondent could envision expanding the crowdsourcing efforts further.

Prediction markets could be used to help agencies with a wide range of forecasting needs, though, to maintain interest from participants, it would likely be best used for short-term forecasts, which could be proven or disproven in a relatively short timescale. Otherwise, the incentives would need to be for participation rather than accuracy, since the potential payoff would occur too far in the future. Within short-term forecasting needs, prediction markets would be well suited for fast-moving technology development cycles, which have few indicators that could be tracked. In these cases, properly developed questions and incentives could be used to get experts with inside knowledge to participate, giving rise to knowledge that would not be otherwise accessible to Federal experts.

B. Alert Capabilities

A respondent from BIS’s Office of Technology Evaluation suggested that an alert tool that raises “red flags” when a pre-determined threshold is crossed could be developed to alert an analyst to the need to conduct an in-depth analysis. In general, such a tool would involve having analysts first determine what future states they are concerned about. Then, they could determine what indicators would give information about the likelihood of those future states occurring, and the thresholds for those indicators at which the analyst wants to be alerted. These tools are distinct from forecasting tools because they do not give any information about the future; they simply report on information from the past and present.

However, the red flag implies a future, because the analyst, by determining the relevant information inputs and thresholds, sets up a relationship between the information passing a threshold and a potential future state.

This class of red flag capabilities could support a range of analysts by allowing the user to specify the type of input data and threshold. In basic research applications, a program manager might want the tool to draw from certain scientific journals or conference proceedings, and the thresholds could be counts of key words or authors appearing, or the co-occurrence of key words and authors. Analysts that look at technologies in later stages of development might have interest in the tool drawing from patent applications, or the appearance of key words in trade journals. Because of the range of customization possible, this class of tool could potentially be used to support short-, medium-, and long-term forecasting efforts.

C. Tracking and Summarization Capabilities

Many interview respondents discussed a desire to be more aware of all of the information relevant to their fields, without specifying any desire for predictive technologies. While this task may be seen as simpler, several capabilities that are currently desired by the interview respondents have not yet been realized. In some cases, the agencies seem to be unaware or unable to use existing technologies. (This lack or ability is discussed in more detail in Chapter 2, Section D, and existing tools and technologies are discussed in Appendix C.) In other cases, there is fundamental research needed to develop a new capability or tool. These needs are discussed in the subsections that follow.

1. Tracking Technology through Name Changes

As technologies move through the maturation cycle from the research phase into applications and product development, the same product or entity may be referred to by different names through the process. Likewise, data sources reporting the technology and the terminology and language associated with it also change. For example, it is often the case that, as a technology matures and products move from research to commercialization phase, one set of terminology diminishes and a different set of terminology emerges in the literature. One of the challenges associated with tracking technologies over a long term is to be cognizant of the name and terminology changes associated with it over the life cycle of its development. Techniques to automate tracking of this information would be very useful.

2. Identifying and Tracking Critical People in a Field of Research

The issue of determining critical people in a field of research was brought up in multiple interviews. Respondents at AFOSR consider one of their chief roles to be investing in people. They expressed interest in tools to identify leading scientists in a new

or emerging area of research, as a way to not only understand the state of leading edge research in the field but also identify promising people to invest in. In addition, they would like to be able to identify which young investigators have the most promise. A similar interest was expressed by the respondent at the NIBIB, who said that adding a capability to identify critical people in the biomedical research networks would strengthen current efforts to manage research portfolios. Tools that have the capability to provide a people forecast by tracing how people coalesce and how fields grow as a result could also be of interest to program managers in various agencies.

The indicators of a researcher's success in innovating and commercializing research technology in the field of biotechnology have been studied by Lynne Zucker and Michael Darby, and could be used to inform the development of new tools. Zucker and Darby refer to biotechnology researchers that lead both scientific innovations and commercialization of technologies stemming from the research as "star scientists." They contend that knowledge, particularly when it is new, is embodied in particular individuals and cannot diffuse rapidly (Zucker and Darby 1998). They have also showed that close collaborations between star scientists in academia and industrial scientists were needed to accomplish commercialization of the breakthroughs, and that where and when star scientists were actively producing publications were key predictors of where and when commercial firms began to use biotechnology (Zucker and Darby 1996). A social network map of researchers in which collaborations between academic and industrial scientists are highlighted could be used to help analysts identify researchers and innovations to track.

3. Organizing and Visualization Information

In many interviews, respondents indicated that a tool that organized and displayed information would be extremely useful, especially if the tool had intuitive visualization capabilities. Tools that could potentially be used have not been adopted by the respondents interviewed for this project. (Two such tools are Sci^2, which is an open source tool, and IN-SPIRE, developed by Pacific Northwest National Laboratory, both of which are discussed in Appendix C.) This suggests that (1) respondents are unaware of existing tools; (2) they do not have the time or financial or personnel resources to acquire the tools; or (3) the tools do not fully meet their needs. Discussions indicate that, to some extent, the current tools do not fully meet their needs. A fully developed organization and visualization tool that would be useful to agency personnel would be one that allows users to select data sources of interest and suggests additional, complementary data sources to supplement the user-selected data sources. The tool would continuously receive updates from those data sources. The tool could then have a number of different analysis capabilities such as: (1) summarizing the information within a single data source or across data sources by topic

modeling or generating word clouds;[8] (2) trend analysis, which would allow the user to look at the change in usage of a term or topic over time; (3) highlight new terms or topics; and (4) allow the user to examine co-occurrence (this could be applied to words in a document, authors of publications, etc.). If such a tool were made flexible enough to accommodate different data sources, analysis types, and user-specified queries, it would be highly desirable for analysts across a wide range of missions.

D. Discussion of the Desired Capabilities of Automated Tools

While there does not appear to be a single tool or capability that is likely to meet all requirements, there is definite interest in forecasting, alert, and tracking and summarization capabilities that could be tailored to specific goals or missions. While the specific applications of the capabilities would vary, some common desired characteristics emerged, based on the usage model of the tools and the culture of trust and acceptance of automated tools in providing input to the decision-making process. The common desired capabilities for tools are (1) that they present information in an easy-to-visualize way (discussed above); (2) that they are customizable to a user's specific needs; and (3) that they are trustworthy.

A tool's customizability is important because of analysts' different forecasting needs. For instance, the desired timescale of forecasts varied from near term (approximately 1 year) to long term (approximately 30 years). Additionally, the level of certainty desired of forecasts varied significantly. In general, the level of desired accuracy and precision changes based on the timescale of the forecast (i.e., near-term forecasts need to be more accurate and precise than long-term forecasts).[9]

The trustworthiness of a tool is important because, as described by multiple respondents, analysts put their credibility on the line when they bring information to decision makers. The analyst needs to be comfortable with the tool's methodologies. Therefore, an important requirement for any tool is that it must not be a black box, but has an audit trail that allows the methodology (for forecasting or other tool capabilities) to be transparent

[8] Word clouds show the popularity of different words in a single document or set of documents by creating a visualization of the words used most frequently, in which the font size of the word correlates with the number of times that word is used.

[9] While users would like forecasts with high levels of certainty, users do not currently have a way to quantify their current accuracy, precision, or recall; therefore, they do not have a sense of what these numbers should be and do not feel strongly about the level at which a tool should perform.

4. Discussion and Implications for IARPA's Technology Forecasting Efforts

One of IARPA's roles is to transition research results to agency partners in the IC. While one of the goals of this project was to help inform IARPA's development of automated technology forecasting tools, the interviews revealed many obstacles that IARPA will face in trying to develop tools that will transition from a research phase to operational use. In this chapter, we discuss these obstacles and present recommendations for IARPA.

A. Current State of Technology Forecasting

We found a significant amount of variation in forecasting activities within the Federal Government in terms of the timescales of interest, the level of automation currently used or being pursued, and the level of trust in automated methods for decision-making. Few of the interview respondents currently use automated tools of any kind, whether or not they have a technology forecasting application. Barriers to adoption of tools include: available tools not suiting agency needs, comfort with the current process, lack of time to train personnel to use tools, and prohibitively high tool costs. In addition, interview respondents cited a lack of trust of automated methods both for analysts and for decision-makers.

While the interview respondents are interested in gaining information about future technology characteristics and applications for short-, mid-, and long-term timescales, multiple agencies for whom part of the mission is to be aware of emerging technologies are focusing on currently available new technologies and applications rather than future technologies or applications. This seems to be due to a combination of two factors: (1) analysts are overwhelmed by the volume of information they need to be aware of and (2) technology development cycles may be too fast for analysts to keep up with the technology. Both of these factors are linked to the general lack of tool use in the Federal Government. Increased use of tools could help analysts maintain awareness about new developments and organize the vast amount of available information.

B. Recommended Capabilities to Develop with IARPA Programs

During interviews, respondents identified specific capabilities that could help them with their forecasting work, as well as general needs that could potentially be addressed by automated tools. The automatable capabilities can be divided into three categories: (1) tracking and summarization capabilities, which give the user information about the

current state, contextualized by the past; (2) alert capabilities, which would flag a user if a pre-determined potential future state is likely to occur, and (3) forecasting capabilities, which provide qualitative information about a future state.

Tracking and summarization capabilities were the most commonly mentioned, with many respondents expressing a desire for tools to assist with information summarization and situational awareness. These tools could summarize the state of a research field, a technology, or a network of people. One possible reason for interest in summarization tools over forecasts could be an issue of prioritization. The respondents may feel that they are inadequate at "keeping up" with the current state of their field, and that decisions are too often made on the basis of incomplete or anecdotal information simply because it is beyond the capability of any analyst (or decision-maker) to be fully updated with all the information that should ideally provide input to the decision-making process. Decisions are made, regardless of whether the decision-maker has complete information. An automated approach for information summarization would provide a more comprehensive basis for decisions than decision-makers currently have.

Alert capabilities could flag analysts when an indicator passes a pre-determined threshold, notifying them to focus their investigation on a particular issue. While not a forecasting tool, alert capabilities could be used to inform analysts of what needs to be investigated further, which could help them understand potential future threats and opportunities.

Within the desired forecasting capabilities, interview responses mapped onto two established techniques: extrapolation and trend analysis, and prediction markets. Extrapolation and trend analysis tools would likely be most useful for agencies that are focused on forecasting technologies in middle to late development stages, since trend analyses work best when they have a substantial time series of data to draw from. Prediction markets would be best used for short-term forecasts, which could be proven or disproven in a relatively short timescale. In addition, the number of interview respondents that discussed the need to understand whether a new technology is likely to have military applications suggests the creation of a new tool, one that would calculate the probability that a technology will become dual-use, or have both civilian and military applications.

C. Considerations in the Development of User-Oriented Tools for Technology Forecasting

For a tool to be accepted by a user, it must (1) present information in an easy-to-visualize way; (2) be customizable to a user's specific needs; and (3) be trustworthy. Each of these characteristics is discussed in more detail in the subsections that follow.

1. Visualization

A tool that organizes and displays information in an intuitive way would help analysts, regardless of whether the tool has any predictive component. Visualization is a key component for tracking and summarization tools, as well as for extrapolation and trend analysis tools, which would allow the user to extract key information from a body of data inputs.

2. Customization

One challenge that IARPA will likely face in developing tools for use in the Federal Government is the high degree of specificity desired by potential users, which may make it difficult to develop an "all purpose" tool. Even when users are interested in broad technology horizon scanning activities, they are examining technologies within the context of their mission and goals. Given the variety of use cases that the interviewed personnel described, a single tool or capability is not likely to meet all the requirements.

3. Trustworthiness

Mistrust of automated tools is likely to be a significant barrier to transitioning a technology forecast. This lack of trust is reflected in the desire for transparency in a technology forecasting tool. Factors that are non-intuitive but strong predictors would likely have a low rate of acceptance by users. This also limits the desired complexity of technology forecasting tools by analysts. While respondents did not acknowledge that they had this concern, they could be concerned that an automated forecast could supplant their judgement in a way that subject matter experts do not currently do. As researchers and analysts, their job is to gather information and use their expert judgement to determine the future implications of that information. If a technology forecast determines future implications automatically, the respondents may be concerned that the forecasts would reduce the need for human analysis.

D. Conclusions

In the short term, for a technology forecast to be accepted by a user, it needs to fit into the current workflow and decision-making structure. Right now, automated technology forecasting tools are not used directly for decision-making. This may be part of the desire for summaries compared to forecasts, since respondents encounter summaries in their job currently, so they are more familiar with them, and know how better summaries would fit into and improve their current workflow. A red-flag or alert system could easily be integrated into the current workflow, since it would run in the background, and prompt the analyst to investigate certain topics further. However, automated trend analysis or crowd-sourcing tools are not widely used and therefore analysts would need to adjust to using these tools in their current processes.

Respondents overwhelmingly expressed that the role of the human in the loop was critical to the use of forecasting tools in the decision-making process. An output from a tool, according to respondents, would most likely then be further interpreted, contextualized, and explained by analysts prior to being elevated to the level of a decision-maker. Therefore, any tool should be designed so as to aid rather than to supplant the role of the analyst, and should not be operated in a stand-alone fashion.

Appendix A.
Interview Methodology and Guide

Sampling

Because there is little information currently available on who uses technology forecasting and technology forecasting tools across the Federal Government, random sampling or other more systematic sampling was not possible. Instead, a primarily respondent-driven sampling method was used to identify and facilitate contact with appropriate individuals. An initial list of respondents was drawn from the Technology Watch and Horizon Scanning Community of Practice. Additional respondent information or candidate government offices were provided by original respondents. Because of the limitations of this sampling methodology this report does not claim to cover all users of technology forecasting within the Federal Government. Every effort was made, however, to cover a broad range of agencies in the IC and DOD, as well as elsewhere.

Interview Guide Development and Interview Procedure

Subject matter experts from both within and outside the government were interviewed for background material and context in the development of the questions for the semi-structured interview. Initially, two interview guides were developed: one for primary users of technology forecasting tools and another for high-level end-users of forecasts and high-level decision makers. However, it became clear during our initial interviews there were not many primary tool users and that the distinction between forecasters and decision makers was not as distinct as initially thought. Because of this, only the interview guide for high-level end-users was used for each interview and additional, specific questions were added based for the specific role of the respondent.

Each interview was semi-structured and based on the same interview guide. All interviews were conducted by the same core interview team. Additional interview questions were developed specifically based on the role of the respondent and the mission of their office or organization.

General Interview Guide: Use of Technology Forecasting Tools in Decision-Making—Federal Government Personnel

Screening questions:

- Do you use technology forecasts?
- Are you familiar with currently available technology forecasting tools?
- Do you have a need for technology forecasts and/or technology forecasting tools?)

Introduction of Personnel

Introduction and Informed Consent

The Office of the Director, National Intelligence, Intelligence Advanced Research Projects Activity (IARPA) asked the Science and Technology Policy Institute to provide information on the ways that technology forecasting and technology forecasting tools are included in the decision-making process within the Federal Government. We would like to ask you some questions about technology forecasting and related tools and your perception about their utility. Participation is completely voluntary and you may refuse to answer any questions or withdraw your consent at any time. We would like to audio-record our conversation with your consent, and if you'd like to tell us something that is off the record, we will stop recording and writing until you tell us that we can start again. Recordings will be erased after transcribed, and transcripts will be disposed at the end of the project. Recording and transcripts will not be shared with IARPA—only summaries and aggregate data will be shared. May we have your permission to record the interview and proceed?

Interview goals:

- To understand the role of technology forecasting in decision-making
- To understand the use of existing technology forecasting tools and their perceived benefits and shortcomings
- To understand potential current and future needs in technology forecasting and technology forecasting tools

IARPA POC:

Individual Background:

- Date:
- Agency:
- Office/Department/Division:
- Office/Department/Division Function:
- Do you currently use technology forecasting/projections?

- If no, how familiar are you with technology forecasting and technology forecasting tool?

Use of Technology Forecasting/Projecting

- Does technology forecasting have a formal role in your office?
  - If yes, what is that role?
  - If no, do you use technology forecasting and how?
- Is technology forecasting used officially in decision-making in your office?
  - If so, how?
    - What kinds of forecasts (predicting what? E.g., performance vs. technology)?
  - If not, how is it used?
- How exactly do you use technology forecasting?
- Are any automated forecasts used in decision making within your office?

Forecasting Tools

- What kinds of tools do you use for your technology forecasts?
  - Specific for technology forecasting?
  - What kinds of technology are you interested in forecasting/predicting?
  - Source?
  - Have you used any other tools or approaches in the past?
- Can you tell us about some of the benefits and drawbacks to the forecasts and the forecasting tool?
  - Broad trends or specific technologies?
  - Time frame for forecasts
  - Precision
  - Accuracy
  - Interface
  - Data input
  - Data output
  - Data visualization

- Are you aware of other tools?
  - If so, which?
  - What are their benefits/drawbacks?

Data for Technology-related Decision Making

- Do you regularly use any data (reports, databases, etc.), outside of formal technology forecasts, to aid in your decision-making?
  - If so, what are those sources?
    - Publicly available?
    - Purchased? Source?
  - How are these sources used in your decision-making?
- Is your analysis and/or decision-making limited by data available? If so, how?
  - Is there any other data out there that you can't access?
  - If not, what kind of data do you need?
- Are there places where an automated tool for data analysis or data visualization might help?

Attitudes about Forecasting Tools

- If you are currently using a tool, how much do you trust this tool?
- If you stopped, why did you stop?
  - Did you encounter specific problems?
    - Cost?
    - Usefulness?
    - Interface?
    - Data?
- If you don't currently use tools, could you ever be convinced to use a forecasting tool?
  - Why or why not?
    - What criteria (standards) would the tool have to meet?
- Are you aware of the kinds of tools that are currently available in technology forecasting?
  - If so, what is the source of your information?

- If you don’t currently use forecasting or forecasting tools, are there problems/questions that you currently deal with that might benefit from the use of technology forecasting tools?
  - What kinds of questions?
  - What would your ideal tools be able to do?
- If you don’t plan to use automated forecasting, why not?
  - What barriers (trust, data issues, etc.) would you have to overcome?

Appendix B.
Summaries of Interviews

The following summaries are based on STPI research staff's interviews with agency personnel as well as background research.

Air Force Office of Scientific Research (AFOSR)

AFOSR oversees a basic research portfolio of over 1200 grants invested globally at universities, industry and internal research programs.[10] Recently, AFOSR began an effort in collaboration with the Basic Research Innovation and Collaboration Center (BRICC). A partnership with the Virginia Tech Applied Research Corporation (VT-ARC),[11] it focuses on the use of bibliometrics and development of related tools to inform decisions related to technical research investment, and promote a cohesive investment strategy. Analytic methods are particularly useful in situations where resources are scarce (such as the international office), the investments are big, the field is diverse and the Air Force can make a significant impact through its investment, such as reconfigurable electronics.

At this time, AFOSR is interested in using analytics to support their requirement to report on the impact of their portfolio. AFOSR delivers briefs on their portfolios first to the AF acquisition office, which reports to the Chief Office of the AF (which reports to the Congress), and ASD(R&E).

AFOSR would like to increase their use of analytics in investment decision-making.[12] One area of particular interest is the application of analytics on issues of personnel and research networks. Since AFOSR invests primarily in people, they are interested in new ways to predict on which young faculty and rising researchers AFOSR should focus their investments to ensure success. The ability to identify promising researchers is seen as important as people represent longer-term investments with better outcomes than research projects. The current approach to identifying new researchers is to ask current principle investigators for their recommendations. Tools that can provide a people forecast by tracing

[10] Wright Patterson Air Force Base website, "AFOSR—About," http://www.wpafb.af.mil/library/factsheets/factsheet.asp?id=19470.

[11] BRICC website, "BRICC Projects," http://bricc.vt-arc.org/about.

[12] AFOSR had previously commissioned STPI to examine the utility of different tools to identify emerging areas of research. As part of this study, AFOSR had STPI research staff evaluate FUSE for use by AFOSR program managers.

how people coalesce and how fields grow as a consequence and attempting to predict which young investigators have the most potential for useful research in a given field.

Program mangers currently use widely available tools like Web of Science (publication database) and Google Scholar. The Basic Research Innovation Collaboration Center, established in partnership with the Virginia Tech Applied Research Corporation develops tools and methods for data analytics that are used by AFOSR for portfolio analysis and analyzing trends in science and technology. However, the program managers still rely heavily on subject matter experts to understand current and future states of technology. Tools to assist in reporting, information capture and the ecosystems of communication were suggested as useful directions to consider.

The respondents that STPI research staff spoke with believe that a forecast should be a hypothesis to be tested, rather than the final word. They also believe that there should always be a human in the loop to interpret forecast results for policymakers as the "burden of proof is so much higher on machines" At present, one of the barriers to using tool to provide input into decision-making is lack of trust in automated forecasts. Trust needs to be built and earned at the management level. One way to build this trust is to make the levels of uncertainty transparent by embedding uncertainty quantification in the methodology or other methods to ensure that the wrong message does not get presented to higher level decision-makers.

The respondents also mentioned that there is fear that a forecasting tool will replace a program officer. However, those who champion automated methods believe that they could be used to support the analyst and as a check against cognitive bias and lend credibility to decisions.

Central Intelligence Agency (CIA), Directorate of Science and Technology

The official at the CIA's Directorate of Science and Technology (DS&T) interviewed for this task believes that the CIA uses technology forecasting, although not adequately. The CIA is a customer for science and technology intelligence forecasting and geopolitical forecasting where S&T plays a role. Forecasts are used to plan research investments, tactically and strategically. The planning follows a 3-year budget cycle starting with a major issue study. In year 3, there is a consolidated intelligence investment strategy followed by a congressional budget justification.

There is no in-house tool development within DS&T; they believe that the government is best served by finding a niche where the private sector cannot or will not play, rather than being in competition with the private sector. In-Q-Tel, the CIA's venture fund, is a conduit to private sector startups. They invest in dual-use tools that are being developed for commercial sector marketing and commercial sector forecasts. In-Q-Tel is

looking at capabilities of companies such as Recorded Future, which use machine-learning based forecasting approaches.[13] Lab41, an In-Q-Tel owned and operated venture, is a testing ground for applying emerging analytic techniques to intelligence community problems.[14] These tools are sourced by the CIA's Open Source Center for forecasting, and used by agency analysts. The analysts are seen as essential to the process, as they come in to close the loop on answering the "so what?" question.

Defense Threat Reduction Agency (DTRA), Research and Development Directorate (J9)

DTRA's mission is to safeguard the United States and its allies from weapons of mass destruction (chemical, biological, radiological and nuclear) and high yield explosives by developing capabilities to reduce, eliminate and counter the threat.[15] J9 is DTRA's research and development division, and funds activities ranging from basic research through development and integration of technologies.[16] The types of decisions they are trying to inform are whether research should be initiated in an area, an appropriate level of monitoring for a potential threat, preventing future WMD threats etc. They look at things on two scales, intent and capability.

One aspect of DTRA J9's role is to anticipate emerging challenges to be able to provide timely responses to their customers, who are combatant commands and services. The combatant commands and services informs DTRA J9 about their current needs, but this introduces a lag, since ideally, DTRA would be able to address potential threats before they become a problem.

Forecasting and prediction are seen as a challenging activities associated with many limitations. Much of the information available today is based on anecdotal evidence and not analytically driven. Instead of predictions, DTRA focuses on approaches for looking at observable trends. The thought is that once you document what you are seeing from a trends

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13 Recorded Future website, "Out-Innovate Your Adversaries with Real-Time Threat Intelligence," https://www.recordedfuture.com/.

14 Lab41 is a testing facility for big data analytics that is operated by the non-profit funding arm of the CIA called In-Q-Tel. The operation located in Silicon Valley is unclassified. It was designed to enable private sector software developers and engineers to collaborate on developing techniques to apply analytics to massive amounts of data for the IC. According to Lab41, projects address data visualization, social network analysis and statistical modeling of structured and unstructured information. "Challenge teams" operate out of a facility based in Menlo Park, California, working on selected projects within a 3–12-month time frame. Lab41 website, "Where Experts in Needles & Haystacks Work Together," https://www.lab41.org/.

15 Defense Threat Reduction Agency website, "Missions," http://www.dtra.mil/Missions.aspx.

16 Global Biodefense website, "DTRA Seeks Counter-WMD Research Support Services," http://globalbiodefense.com/2014/08/28/dtra-seeks-counter-wmd-research-support/.

perspective, you can do an analysis. Essentially, they would like to take a Net Assessment[17] and convert that into "news you can use."

DTRA has been brainstorming, for several years, on ways to integrate different approaches; no single methodology or approach has everything they need. The process they would like to have in place is to (1) look at trends that are either clearly impactful or possible impactful, (2) assess those trends, (3) have DTRA and the CWMD community of practice look at the assessments, (4) inform intelligence collectors, (5) circle back and iterate with people in the IC.

DTRA J9's goal is to institutionalize technology forecasting and they are open to leveraging IARPA's activities. Within their context, an automated forecasting tool would be used in the following ways (1) to validate known information, (2) to identify new application of existing technology, and (3) to tie less known technologies with new applications. Their ideal forecast would look at a timescale of 5–15 years out. The expectation is that the tool provide defensible results that are analytically sound; transparency is a requirement. Any certainty greater than 50% would be acceptable to them.

Department of Defense (DOD), Office of Technical Intelligence, Assistant Secretary of Defense for Research and Engineering (ASD[R&E])

The Office of Technical Intelligence analyzes global science and technology activities to inform future DOD investments in workforce, infrastructure and research funding. The OTI conducts technology watch and horizon scanning activities with the following goals: (1) "identify[ing] emerging S&T areas that will enhance operational capability in the next 10–20 years," (2) "assess[ing] scientific areas that should be included in the long-range (10+ years) research strategy," and (3) "provid[ing] context to understand the S&T that will result in significant new discoveries.[18]

The respondents at OTI believe that decisions today are not being informed by data analytics or technology forecasting to any great extent. They believe that people are still seeking help to understand the current state of things, which analytics can help answer. Accordingly, they are focusing not on data-driven decisions but data-enabled decisions. Their current focus is on developing analytics for basic science. These analytics would be used by program managers to understand gaps and emerging areas in their investment portfolio, centers of excellence, as well as to identify lead researchers and young and rising researchers in their area. (Automated tools are used as part of the process, not all of it; tool

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[17] Net Assessments are intended to look long term (20–30 years) into the military's future.

[18] Department of Defense Research & Engineering Enterprise website, "Science & Technology Corner, Technology Watch and Horizon Scanning for the Department of Defense," http://www.acq.osd.mil/chieftechnologist/cto/cto_TWHS.html.

results are supplemented by inputs from subject matter experts which are then used by analysts to interpret such that the resulting information is relevant to the perspective of a decision-maker). Their methodologies are: (1) horizon scanning, the detection of changes and emergence, despite a weak signal to noise ratio, and (2) technology watching, the collection all possible information on a technology, actionable intelligence. OTI leverages commercial technology forecasting systems as well as invests in the development of new forecasting approaches (such as TechWatch) that integrate multiple data analysis streams and a suite of S&T forecasting tools.

In the future, OTI will focus on identifying enabling technologies for a future capability. Their approach for this is to identify a capability of interest, break it down to the technologies, break it out to the components and start with developing a taxonomy for that level.

The respondents see forecasting as an iterative process with refinements from SMEs; the idea is for the data to queue up the SME. They see their decision-making structure as consisting of the output of an automated process combined with subject matter expertise providing information to the interpreter who provides their input to a decision-maker (such as the Director of the Office of Technical Intelligence) who then provides it to the higher level decision-maker (such as the Assistant Secretary of Defense for Research and Engineering).

The respondents see the role of humans "in the loop" as necessary to provide context and validation to the question and tool output also the presence of a human helps to build trust in the forecast, as in their experience, people trust people, not tools.

This group does not see long-range forecasts (beyond 5 years) as within their capabilities; they are targeting the 2–5-year time frame.

Energy Information Administration (EIA)

EIA produces technology forecasts for energy demand by sector and type of fuel. The forecasts are based on the National Energy Modeling System, which is an integrated model of the U.S. Energy demands linked to a macroeconomic model, developed internally at EIA. Inputs to the model include resource availability, technological choice and characteristics, demographics and global energy market interactions. For newer technologies with less established markets, historical precedent and limiting factors are factored into the projections.

The EIA's primary product is the Annual Energy Outlook, which is published for external customers including the Congress. Forecast timelines are typically 1 to 2 years, but projections for longer timescales are also conducted. Projections are provided at the Census level of detail. Sensitivity analysis using test cases is part of the modeling activity

Government Accountability Office (GAO)

GAO prepares technology assessments of current and emerging technologies to understand implications, challenges and opportunities for "Federal agencies and departments and their wider impact on American society."[19] Topics for these studies are based on current and emerging technologies identified by Congress. The studies look at the anticipated trajectory of the technology, cost factors and policy implications including export control, IP and liability. GAO reports and recommendations are for the government, but Congress, not the GAO, makes decisions based on their technology assessments.

The GAO technology assessment staff do not use any automated tools. They rely on literature searches and reviews, searches by library staff, and interviews with experts. An important focus of these studies is the global economic impact of a technology, and this is challenging to forecast. Therefore, they do more cost and economic modeling more than technology modeling.

The respondents said that they would find it useful to identify historical patterns such as those for general purpose technologies like electricity, and apply those patterns to current technologies and technology enablers. Some tools they have liked are the European Parliamentary Team Assessment (EPTA), a mind mapping tool, which helps a team build connections between topics. Issues they see with tools are the signal-to-noise ratio, and the number of technologies that have emerged very rapidly. They feel the text analytics and clustering tools need validation, but ultimately would like to have a data analytics approach.

National Institutes of Health, National Institute of Biomedical Imaging and Bioengineering (NIBIB)

The mission of NIBIB is to improve health through research and development of new biomedical imaging and bioengineering techniques and devices to improve disease detection, prevention and treatment.[20] Approximately 75–80% of the research funded by NIBIB is investigator driven. The remaining research topics come from a variety of sources ranging from top-down direction from the White House to bottom-up needs based initiatives such as platform technologies for mobile health research. NIBIB also collaborates with NSF and DOE.

The majority of the technology identification and assessment work done through portfolio analysis, comparing the current state of what is being funded and with program

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[19] U.S. Government Accountability Office website, "Technology Assessment," http://www.gao.gov/technology_assessment/key_reports.

[20] NIH Almanac website, "National Institute of Biomedical Imaging and Bioengineering (NIBIB)—Mission," http://www.nih.gov/about-nih/what-we-do/nih-almanac/national-institute-biomedical-imaging-bioengineering-nibib.

officers primarily responsible for identifying emerging areas in need of funding or additional funding. InSpire and bibliometric tools are generally used for these analyses. Once potential areas are identified, subject matter experts (usually current or previously funded investigators) experts or formal, public requests for information (RFIs) to identify research areas that are challenges that the institute should tackle. Occasionally, crowd-sourcing is used to gather information and ideas.

Several different types of tools were suggested as being potentially useful to the NIBIB decision-making process: (1) tools for analyzing what factors lead to successful research, (2) a predictive tool that is able to replicate peer review results and then do better than peer review, (3) tools for identifying critical people in research networks (there's a limited grasp of the biomedical workforce), (4) tools to provide information on how grants come together, and (5) tools that can assist in allocating money in more efficiently than is done currently (between short-term and long-term research).

The respondent believes that a human "in the loop" is essential to guide the results of data mining and provide context. One of the barriers to adoption is that the underlying approaches in automated forecasting tools are statistically based, and not informed by context. There is doubt that such an approach would be better than their current methodology for identifying technologies of interest.

Office of the Director of National Intelligence (ODNI), Acquisition, Technology and Facilities

The respondent within Acquisition, Technology, and Facilities at ODNI believes it is not clear that technology forecasting plays a role in meeting the needs of formal policy makers (such as the National Security Council) or helpful in developing formal policies such as crafting Executive Orders and Presidential Policy Directives). Decisions made at this level are characterized by significant internal debate among many people, and a human analyst is needed to sort through issues and provide interpretation and context around information needs—answering questions such as "What does this mean? Why should I care? What should I do?"

The respondent does not currently see any entry points for automated technology forecasting in the decision-making chain, and is not sure when this point will be reached. However, they do see a role in machine sorting of information to support an analyst, but not creating insight.

The office has explored the use of network analysis tools such as Palantir and Gephi and they are comfortable with the methodology used by the tools. The interpretation still needs to be done by the analyst.

The respondent at ODNI believes that trust and credibility of tools (relative to human analysts) are important issues. Decision-makers have to be comfortable with the

uncertainty level of automated forecasts. Tool developers have to also think about transparency and accountability. There are big challenges to be met for inserting automated forecasting in the decision-making process, and focusing heavily on delivering a tool that is easily transferrable will not help accomplish this.

Appendix C.
Technology Forecasting Tools, Techniques, and Aids

Forecasting Methods

- Backcasting: In backcasting, one begins with envisioning a particular future state, and then traces this state backwards in time to the present to determine the pathways, events, or conditions that could lead to this future state (NRC 2010).
- Horizon Scanning: horizon scanning systems systematically gather information to inform policy makers about emerging issues (Habegger 2009). For technology forecasting applications, horizon scanning refers to tools or techniques that provide advance warning or early indications of emerging technologies.
- Prediction Markets: In prediction markets, the collective judgement of group of individuals are used to generate a forecasts about an event or parameter. Predictions are treated "as assets to be traded on a virtual market that can be accessed by a number of individuals…. The final market value of the asset is taken to be indicative of its likelihood of occurring" (Habegger 2009)
- Scenarios: scenarios are "stories about alternative futures focused on the forecasting problem at hand" (NRC 2010), which are used to understand how different factors influence a future state. In technology forecasting applications, scenarios are often used to examine the different possible development pathways for a technology. They can also be used to examine the different technological capabilities desired in different future states.
- Trend Analysis: In trend analysis, a user or tool uses information the past and present to forecast a future state. These techniques assume that "the future represents a logical extension of the past and that predictions can be made by identifying and extrapolating the appropriate trends from the available data" (NRC 2010).

Tools, Capabilities, and Programs

- Forecasting Science and Technology (ForeST): ForeST is an IARPA program whose goal is to "develop and test methods for generating accurate forecasts for significant science and technology (S&T) milestones, by combining the

judgments of many experts."[21] As part of the ForeST program, researchers were funded to run SciCast, described below.

- Foresight and Understanding from Scientific Exposition (FUSE): FUSE is an IARPA program whose goal is to "mitigate technology surprise by the reliable and early detection of emerging scientific and technological concepts across multiple disciplines through automated analysis of the primary scientific literature" (Murdick n.d.). FUSE forecasts emerging scientific and technological concepts by predicting terms (unigrams to 4-grams)[22] that are likely to increase in usage within the next 2–3 years.
- IN-SPIRE™: IN-SPIRE is a software tool developed by Pacific Northwest National Laboratory to organize and visualize information from unstructured text documents. It "determines key topics or themes in each to create a signature for each document in the collection. IN-SPIRE's two main visualizations display representations of the documents in which those with similar or related topics appear closer together."[23]
- SciCast: SciCast was the largest science and technology tournament program.[24] It was run by George Mason University from November 2014 through May 2015 as part of IARPA's Forecasting Science and Technology (ForeST) program.[25] Participants could pose and answer questions related to science and technology developments. Participants could change their forecasts at any time based on new information, which made the SciCast platform a real-time indicator of what participants think is going to happen (Tsarchopoulos 2014).
- Science of Science (Sci2): Sci2 is a tool developed by Katy Börner and Kevin W. Boyack of SciTech Strategies Inc. to study science research and practice. It allows users to input text and run multiple types of analyses, including temporal analysis, geospatial analysis and mapping, topical analysis and mapping, tree analysis and visualization, and network analysis and visualization (Sci2 Team. 2009).

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21 IARPA website, "Forecasting Science & Technology (ForeST)," http://www.iarpa.gov/index.php/research-programs/forest.

22 An n-gram is a sequence of adjacent words from a document. A unigram is made up of a single word and a bigram is a single word plus the word that follows it. An n-gram is a sequence of a word plus the n-1 words that follow it. In general, larger values of n give greater context to the string of terms.

23 IN-SPIRE website, "About IN-SPIRE," http://in-spire.pnnl.gov/about.stm.

24 IARPA website, "Forecasting Science & Technology," http://www.iarpa.gov/index.php/research-programs/forest.

25 The Official SciCast Blog, "About," http://blog.scicast.org/about/.

- Technology Watch/Horizon Scanning (TW/HS): This is a web tool currently under development by OTI within the Office of ASD(R&E) to (1) identify emerging S&T areas that will enhance operational capability in the next 10–20 years, (2) assess scientific areas that should be included in the long-range (10+ years) research strategy, and (3) provide context to understand the S&T that will result in significant new discoveries.[26] It will leverage algorithmic approaches, commercial systems, and information on research investments and outputs.

[26] Department of Defense Research & Engineering Enterprise website, "Science & Technology Corner, Technology Watch and Horizon Scanning for the Department of Defense," http://www.acq.osd.mil/chieftechnologist/cto/cto_TWHS.html.

Appendix D.
Case Studies of Federal Agencies

The IDA researchers conducted case studies of three Federal agencies selected from the set of agencies examined because they each present a distinct opportunity for technology forecasting tools to help improve the agencies' current processes. The three selected for case study were:

- Agency for Healthcare Research and Quality in the Department of Health and Human Services
- Bureau of Industry and Security in the Department of Commerce, and
- Chief of Naval Operations Strategic Studies Group

The case studies consisted of background research by IDA researchers and information from structured conversations between IDA researchers and representatives of the agencies.

Agency for Healthcare Research and Quality (AHRQ)

Background and Goals

AHRQ within the U.S. Department of Health and Human Services runs the Effective Health Care Program and funds "effectiveness and comparative effectiveness research for clinicians, consumers, and policymakers."[27] The goal of the research is to inform health-care decisions, such as clinical guidelines, health care policies, and insurance coverage decisions (AHRQ 2014). The Effective Health Care Program has seven steps to conduct, sustain, and advance the comparative effectiveness research,[28] and this case study examines AHRQ's process for the first of these steps, identifying new and emerging clinical interventions, which is done through the AHRQ Healthcare Horizon Scanning System. The six remaining steps are not discussed since they are not related to technology forecasting.

The Healthcare Horizon Scanning System has been funded since 2009 to inform patient-centered outcomes research investments through scanning emerging healthcare technologies and

[27] AHRQ, Effective Health Care Program website, "What Is the Effective Health Care Program," http://effectivehealthcare.ahrq.gov/index.cfm/what-is-the-effective-health-care-program1/.

[28] AHRQ, Effective Health Care Program website, "What Is Comparative Effectiveness Research," http://effectivehealthcare.ahrq.gov/index.cfm/what-is-comparative-effectiveness-research1/.

innovations.[29] AHRQ's system is the first "publicly available, comprehensive system…for [health care] horizon scanning in the United States" (DeLurio et al. 2015).[30] The goal of the system is to identify emerging technologies or innovations that could meet previously unmet health needs. Examples of emerging health care technologies and innovations include "new (and new uses of existing) pharmaceuticals, medical devices, interventions, behavioral health interventions, health care delivery innovations, and public health and health promotion activities." Originally, the output of the Healthcare Horizon Scanning System was intended to be used for research prioritization. However, in 2010, the Patient-Centered Outcomes Research Institute (PCORI) was created to fund comparative clinical effectiveness research with the goal of determining "which of the many healthcare options available to patients and those who care for them work best in particular circumstances."[31] As a research funding organization, PCORI determines its own priorities, though it may use the output of the Healthcare Horizon Scanning System.

Process Overview

The Healthcare Horizon Scanning System is a non-automated process, the details of which are shown in Figure D-1. Additional details follow. Medical librarians search daily for leads from publicly available sources such as medical journals, scientific literature, company press releases, trade publications, and newsletters. A set of criteria is used to guide the selection of leads, which must be related to AHRQ's priority areas or a cross-cutting area. Based on the relevant AHRQ priority area, subcategory, and topic class, as well as whether it meets a set of criteria, leads are sorted into a list of possible topics. Analysts review the potential leads and nominate topics, which are discussed and voted upon by a larger group that includes analysts, librarians, content team leader, project manager, and other invited staff and experts. Topics that receive a majority of votes are entered into the Healthcare Horizon Scanning System. Once in the system, a topic is assigned to an analyst with relevant expertise for more in-depth research and to a medical librarian for a detailed topic profile. The topic profiles are reviewed by internal and external research experts. Following this review process, high-impact topics are selected and written up in a report. While the high-impact topics only those that have late-phase data, additional topics are in earlier stages of research. These additional topics and the high-impact topics are tracked continually, with the use of automated alerts where possible. Topics are tracked from 1 year prior to Food and Drug Administration (FDA) approval to 2 years following FDA approval.

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[29] AHRQ, Effective Health Care Program website, "AHRQ Healthcare Horizon Scanning System," http://effectivehealthcare.ahrq.gov/index.cfm/who-is-involved-in-the-effective-health-care-program1/ahrq-horizon-scanning-system/.

[30] EuroScan International Network is a European healthcare horizon scanning system.

[31] PCORI website, "About Us," http://www.pcori.org/about-us.

Source: DeLurio et al. (2015).

Figure D-1. Overview of the AHRQ Healthcare Horizon Scanning System Process

While AHRQ does not make policy decisions, the outcome of its work is used in decision-making, and healthcare insurance providers have cited AHRQ research in their coverage plans.

Interest in Technology Forecasts

The Healthcare Horizon Scanning System provides a short-term forecast by looking at innovations approximately 1 year before FDA approval through 2 years after FDA approval.

However, AHRQ is interested in being able to predict further into the future to forecast innovations in medicine.

The AHRQ respondent expressed interest in a system that uses crowdsourcing. For example, Medscape has recently developed Medscape Consult, an "online community for physicians to ask and answer clinical questions and share and discuss clinical challenges."[32] While Medscape is not predictive, the idea of having a wider community nominate topics and contribute opinions is of interest. The respondent also expressed interest in two different types of automated tools: (1) automated search capabilities and (2) automated horizon scanning tools that would allow someone to find out about more about a topic of interest.

Discussion

The AHRQ Healthcare Horizon Scanning System is the most systematic horizon scanning system among those that STPI research staff encountered in the government. With the exception of automated alerts on specific search terms, this system is manual; it relies on librarians, analysts, and subject matter experts, which is extremely labor-intensive. The guiding questions and criteria that help the librarians and analysts illustrate the amount of human judgment required, which is viewed as necessary to the process. All of the steps from lead identification to indexing of terms require some knowledge of context.

A tool that could be useful to AHRQ would be one that automates a subset of the steps in the existing process (a tool that scans the literature, a tool that groups leads into topics, a tool that assigns controlled vocabulary, etc.). It would also be useful to develop tools that could reduce bias in the process by suggesting relevant experts for a given topic, for example. Currently, analysts and experts are used to determine whether a topic is high impact and to analyze those high-impact topics. One step towards an automated system would be to have an algorithm identify whether a topic is potentially high impact, and have analysts and experts review that proposal.

Another way to improve the horizon scanning system would be to develop predictive capabilities that are able to scan more early-stage research and determine the areas of patient-care that could be affected rather than looking at research that is near or at the point of late-stage trials. This could allow for earlier research investment in useful health care technologies or innovations.

Bureau of Industry and Security (BIS)

Background and Goals

The mission of BIS is to "advance U.S. national security, foreign policy, and economic objectives by ensuring an effective export control and treaty compliance system and promoting

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[32] Medscape website, "Medscape Consult," http://www.medscape.com/public/consult-feature.

continued U.S. strategic technology leadership."[33] BIS is "charged with the development, implementation and interpretation of U.S. export control policy for dual-use commodities, software, and technology."[34] As part of this role, BIS needs to first determine emerging technologies that are "dual-use" or have both civil application and applications related to the military, terrorism, or weapons of mass destruction (15 CFR, Subtitle B, Chapter VII, Subchapter C, Part 730, Section 730.3), and then determine appropriate export controls that will promote industry while ensuring that exported technology products do not fall into the wrong hands. According to BIS officials, export licenses are needed for roughly 3% of all exported products; these are typically advanced technology products such as lasers, medicines, electronics and military items. This list of products is regularly updated.

The Emerging Technology and Research Advisory Committee (ETRAC) is a Technical Advisory Committee (TAC) created in 2008 (Federal Register 2008), whose role is the "identification of emerging technologies and research and development activities that may be of interest from a dual-use perspective, the prioritization of new and existing controls to determine which are of greatest consequence to national security, the potential impact of dual-use export control requirements on research activities and the threat to national security posed by the unauthorized export of technologies."[35] The committee comprises accomplished engineers and scientists from academia, industry, Federal laboratories, and government. The Departments of Commerce, Defense, State, and the Intelligence Community must be represented on the committee (ETRAC 2012). The BIS Office of Technology Evaluation (OTE) administers ETRAC and other technical advisory committees and conducts in-depth analysis of critical technologies.

Process Overview

ETRAC comprises members from across the government and private industry (particularly from sectors of interest such as aerospace, optics, and biotechnology). To identify emerging technologies, the committee seeks input from experts from sensor, IT, transportation, and other advanced technology industries and visits relevant national laboratories such as the Army Research Laboratory and the Air Force Research Laboratory. ETRAC also invites testimonials from companies and looks at scientific publications and patents.

To understand the technology evolution and assess the impact of the technology on national security, the committee looks to see who is developing the technology and whether there is a shortage of qualified people. The committee also does an in-depth analysis of the sale of the candidate technologies and assesses the effect on the industry if sales are restricted. ETRAC forecasts 3–5 years out to assess the impact of the technology on national security and economic competitiveness. A list of 20 to 30 initial candidate technologies is reduced to 6 and forwarded for

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[33] BIS website, "About the Bureau of Industry and Security," http://www.bis.doc.gov/index.php/about-bis.

[34] BIS website, "Policy Guidance," https://www.bis.doc.gov/index.php/policy-guidance.

[35] BIS, TAC website, "How Many TACs Are There and What Do They Do?" http://tac.bis.doc.gov/.

action to the Assistant Secretary for Export Administration. OTE, which reports to the Assistant Secretary for Export Administration, reviews these technologies, along with those that have been commissioned by other entities, such as government agencies.

OTE examines each technology on the list and questions whether peer countries have similar concerns about the technology, refines the assessment of where the product is in its evolution, and determines the national security implications of the technology. Export regulations are informed by OTE's results, and BIS can propose technologies for a multilateral export control regime.[36]

No tools of any kind are currently used to identify emerging technologies with potential dual-use applications. The work is done entirely by OTE, ETRAC members, and the external experts recruited by them.

Interest in Technology Forecasts

An OTE representative interviewed for this project suggested the idea of a "red flag" tool that would monitor the acquisition of companies internationally and alert an OSE analyst if a certain number of companies within a given sector were purchased by companies in a country other than the United States. This information could support the OTE's analysis of current foreign availability of critical products and technologies and help OTE evaluate the expected impact of export controls. The OTE representative said that such a tool would have been useful in 2001 and 2002, when a number of aerospace companies were purchased by the European Union. Rather than focusing on gathering the data, the analyst could have been focused on the implications of these purchases after being alerted about them.

Discussion

Currently, there is no systematic, automated process to alert personnel at BIS about emerging technologies that have the potential for dual-use applications. BIS personnel rely on members of ETRAC or other agencies and groups to suggest that the OTE conduct a technology evaluation. This process means that OTE often is evaluating technologies in later stages of development. A technology forecasting approach could be used to make OTE aware of a broader range of technologies at earlier stages of development, ensuring more comprehensive export regulation considerations. While not discussed by any BIS members contacted for this project, a tool that determines the probability of a technology being a dual-use technology could also be useful to help select technologies for investigation by OTE.

[36] The United States participates in four multilateral export control regimes: the Australia Group, the Missile Technology Control Regime, the Nuclear Suppliers Group, and the Wassenaar Arrangement.

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Abbreviations

AFOSR	Air Force Office of Scientific Research
AHRQ	Agency for Healthcare Research and Quality
ASD(R&E)	Assistant Secretary of Defense for Research and Engineering
ATF	Acquisition, Technology, and Facilities
BIS	Bureau of Industry and Security
BRICC	Basic Research Innovation Collaboration Center
CIA	Central Intelligence Agency
CNO	Chief of Naval Operations
CWMD	Countering Weapons of Mass Destruction
DOC	Department of Commerce
DOD	Department of Defense
DS&T	Directorate of Science and Technology
DTRA	Defense Threat Reduction Agency
EIA	Energy Information Administration
ETRAC	Emerging Technology and Research Advisory Committee
FDA	Food and Drug Administration
ForeST	Forecasting Science and Technology
FUSE	Foresight and Understanding from Scientific Exposition
GAO	Government Accountability Office
IARPA	Intelligence Advanced Research Projects Activity
IC	Intelligence Community
IDA	Institute for Defense Analyses
J9	Research and Development Directorate
NASA	National Aeronautics and Space Administration
NEMS	National Energy Modeling System
NIBIB	National Institute of Biomedical Imaging and Bioengineering
NIH	National Institutes of Health
ODNI	Office of the Director of National Intelligence
OTE	Office of Technology Evaluation
OTI	Office of Technical Intelligence
PCORI	Patient-Centered Outcomes Research Institute
S&T	science and technology
SME	subject matter expert
SSG	Strategic Studies Group
STPI	Science and Technology Policy Institute
TAC	Technical Advisory Committee

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14. ABSTRACT

This report examines the current and potential future use of technology forecasts in science and technology (S&T) decision-making to help the Intelligence Advanced Research Projects Activity (IARPA) improve the development and implementation of S&T analytic capabilities. We found that tracking and summarization capabilities could help analysts sort, organize, and distill large amounts of information as well as keep abreast of new developments. Alert capabilities could flag analysts when an indicator passes a pre-determined threshold, notifying them to focus their investigation on a particular issue. Personnel interviewed noted, however, that any tool should be designed to aid rather than supplant the role of the analyst and should not be operated in a stand-alone fashion.

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